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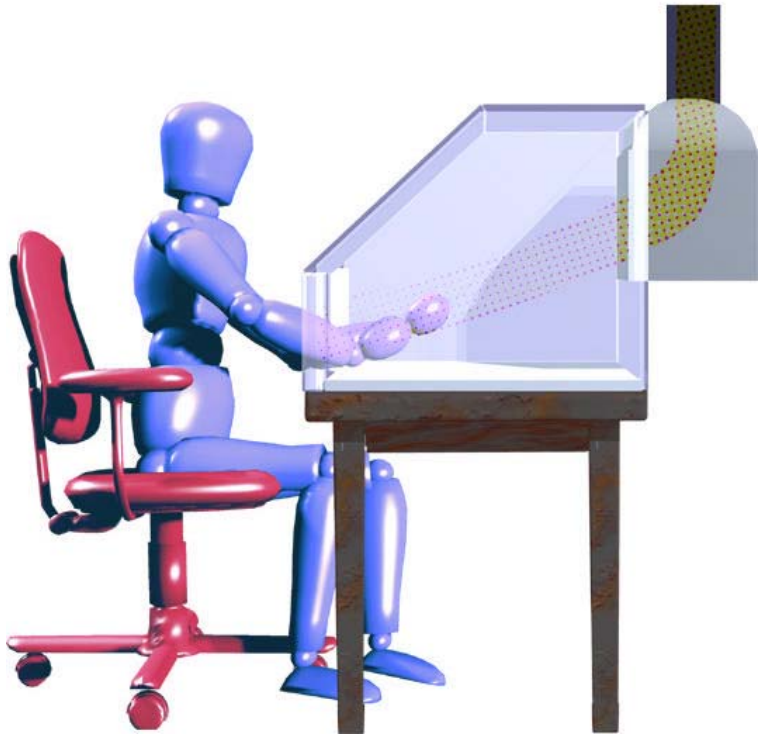
CFD-Driven Design of a Low Airflow, Rapid Recovery Containment Control System™

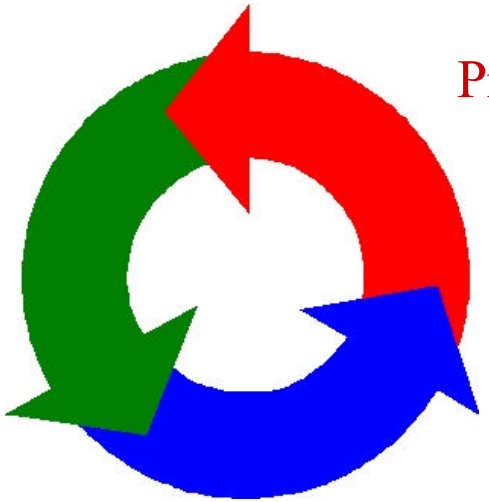


Alexy Kolesnikov
Ray Ryan
Douglas B. Walters

Labs for the 21st century EPA conference. October, 2002
Durham, NC

Efficient Operation. Design Goals.

Task specific custom design loop



Efficiently operating enclosure must:

- Maintain high level of containment protection
- Provide a steady balance reading
- Ensure that materials inside the enclosure are undisturbed by airflow
- Provide ergonomic design and ensure ease of access
- Address energy efficiency concerns

Computational Fluid Dynamics (CFD) Principles

Conservation Law System:

- **k-ε (wall functions) RANS**
- **eddy viscosity RANS**
- **incompressible flow**
- **time iterated to steady-state**
- **er**
- **BC**
- **v BC**
- **nement study**

Conservation of mass:
$$\frac{1}{\rho}\frac{\partial \rho}{\partial t}+\frac{u_j}{\rho}\frac{\partial \rho}{\partial x_j}+\frac{\partial u_j}{\partial x_j}=0$$

Conservation of momentum:
$$\rho\frac{\partial u_i}{\partial t}+\rho u_j\frac{\partial u_i}{\partial x_j}-\frac{\partial \sigma_{ij}}{\partial x_j}-\rho b_i=0$$

Conservation of energy:
$$\rho\frac{\partial e}{\partial t}+\rho u_j\frac{\partial e}{\partial x_j}-\sigma_{ij}\varepsilon_{ij}-\rho s+\frac{\partial q_j}{\partial x_j}=0$$

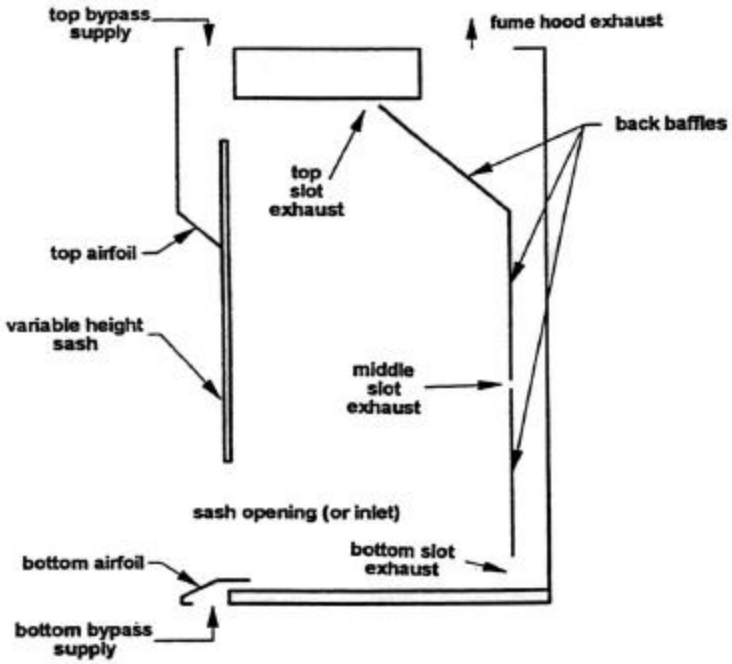
σ – Cauchy stress tensor, e – internal energy, s – distributed heat generation,
ε - strain-rate tensor, q – heat transfer rate by diffusion.

$$\varepsilon_{ij}=\frac{1}{2}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)$$

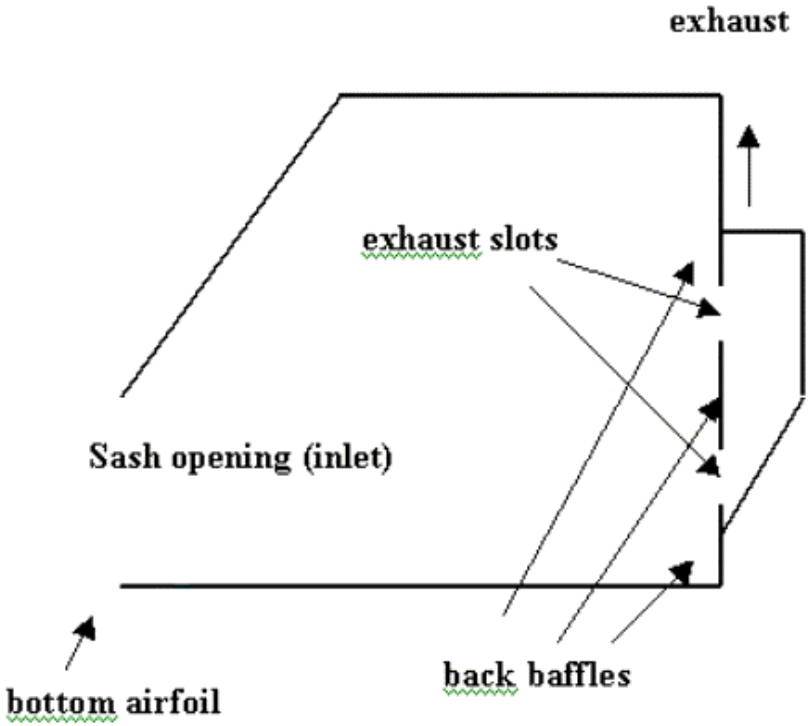
Airflow Distribution Parameters

- Enclosure geometry
- Sash height
- Face velocity
- Operator presence
- Room air currents
- Equipment arrangement inside enclosure

Typical fume hood



Typical Flow Sciences enclosure



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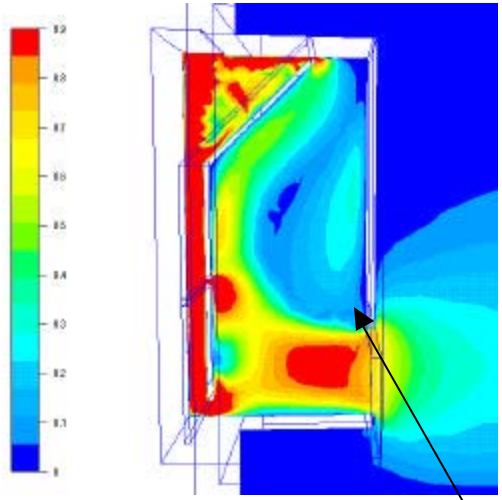
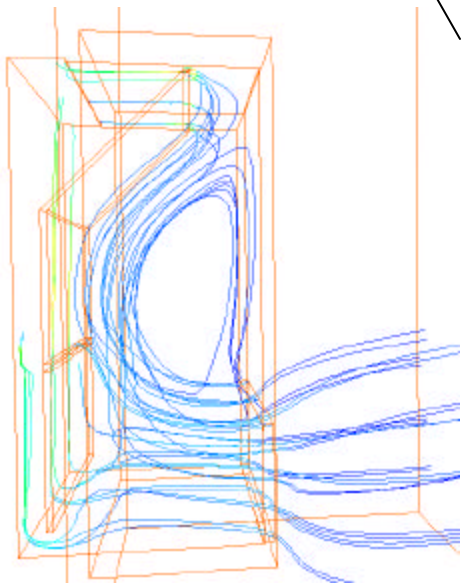
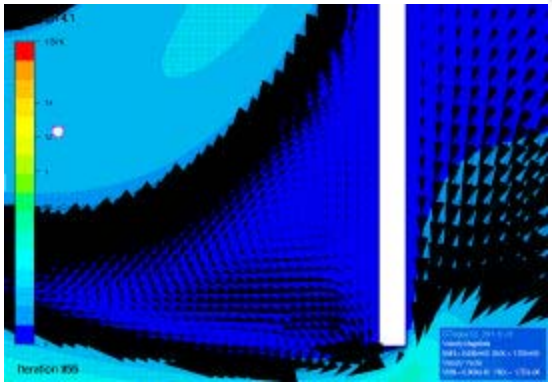
CFD Airflow modeling

Typical fume hood

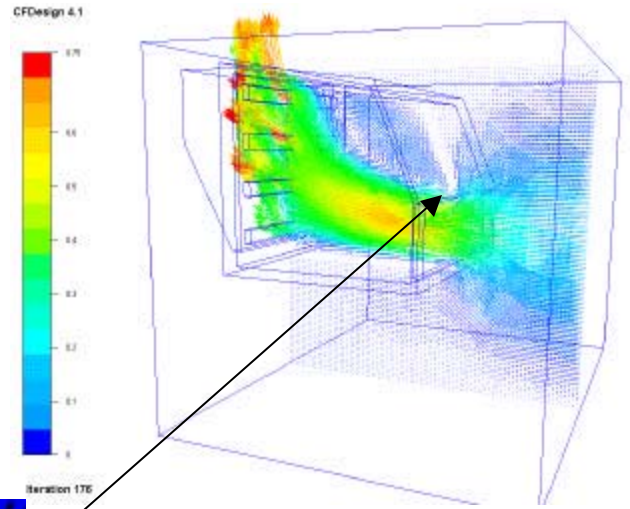


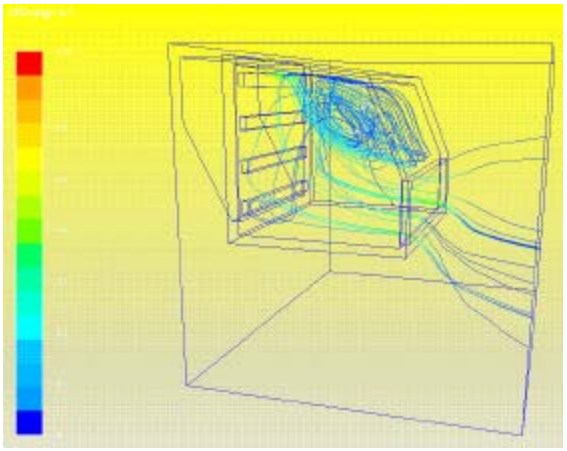


Sash door airflow detail



Typical Flow Sciences enclosure





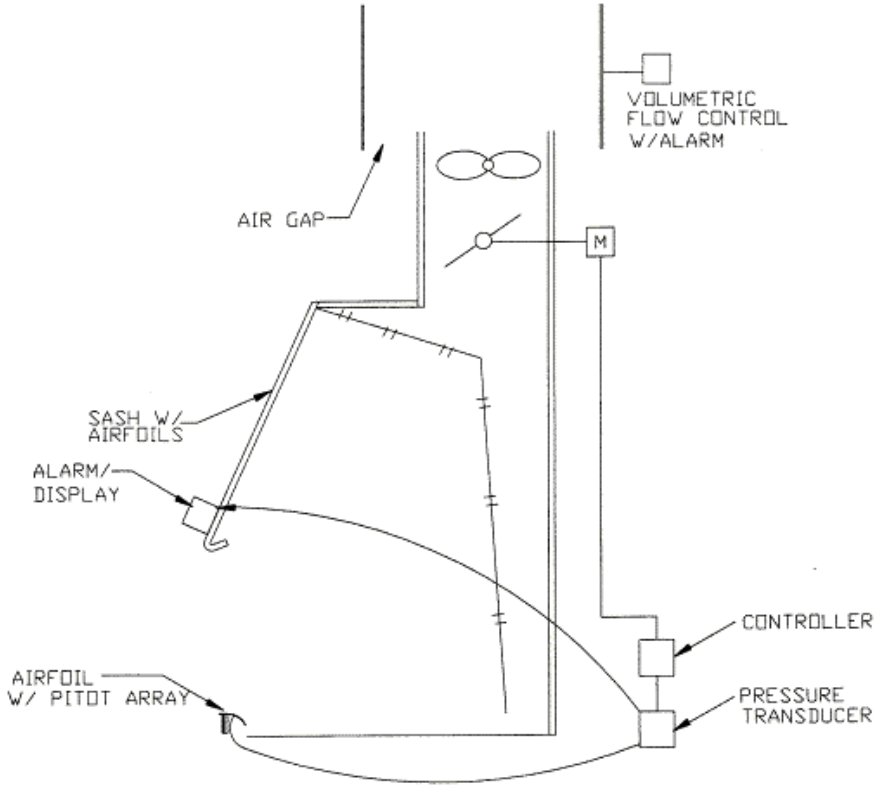
Variable Air Volume Control System

Traditional system design

- Slow or NO response to upset at hood opening
- Indirect flow control measurement (velocity or sash position)
- Primary design focus on energy
- Hood containment not improved by control system performance

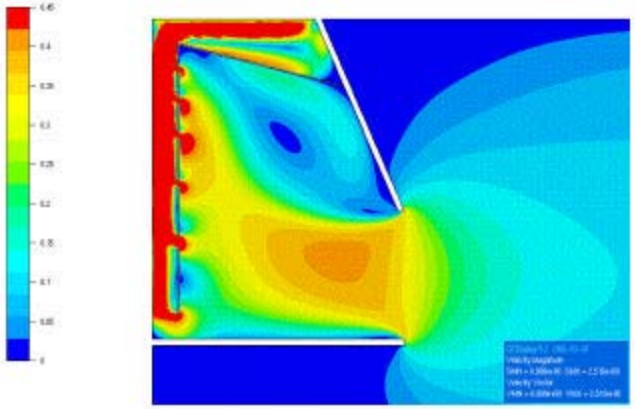
Rapid recovery containment control system

- Virtually instantaneous response
- Direct flow control measurement (pressure)
- Primary design focus on containment / safety
- Additional benefit of reduced energy consumption
- Direct coupling between hood design optimization and containment control system performance

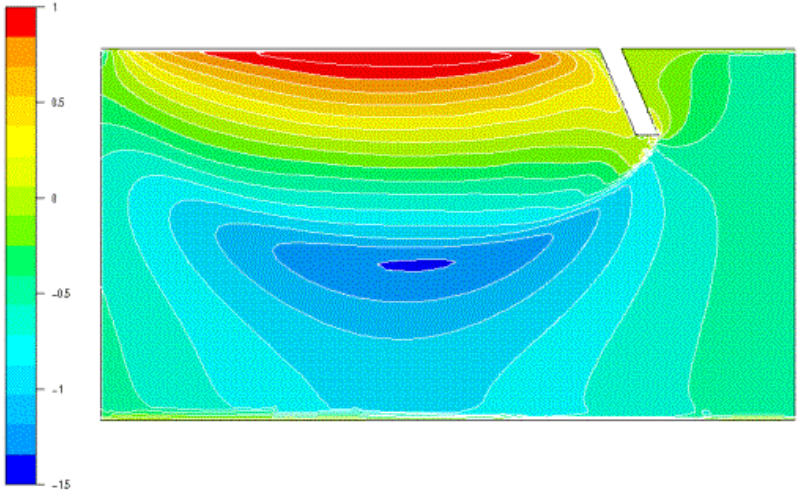


CFD Airflow modeling details

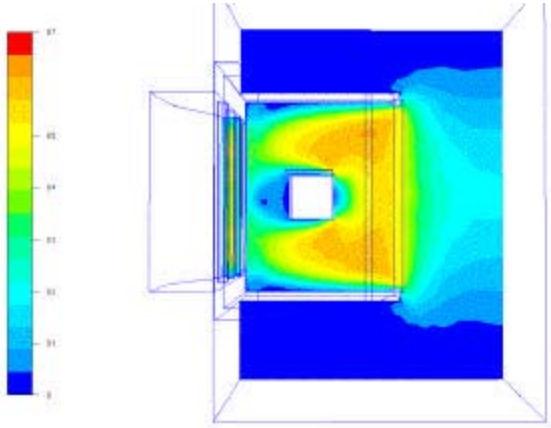
Exhaust slots configuration

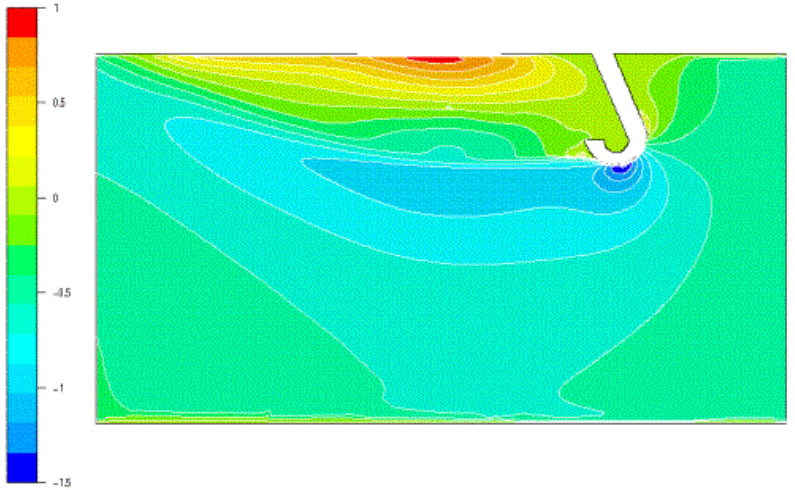


Airfoil design optimization



Equipment arrangement

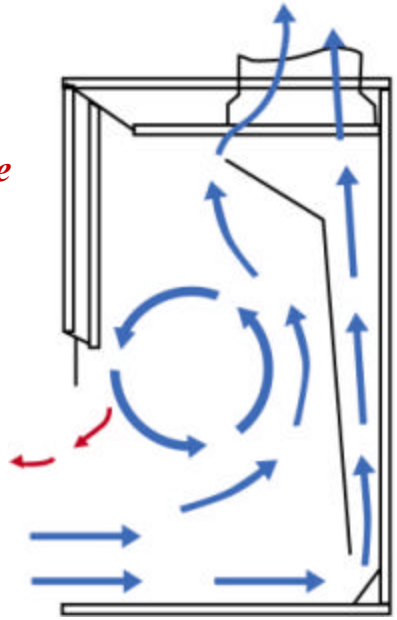




Performance Characteristics

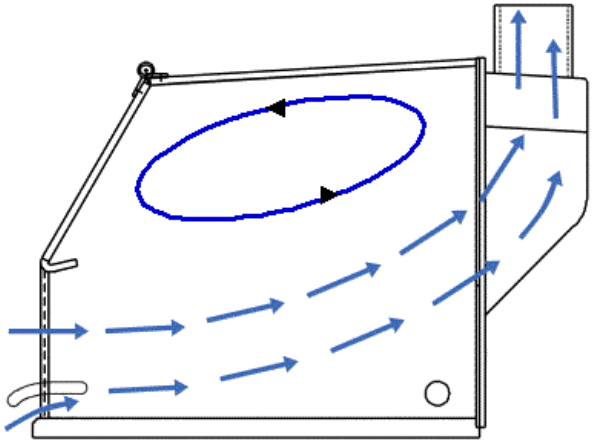
Typical fume hood

Rapid reverse of airflow at face of the hood causes loss of containment while increasing operator exposure



Flow Sciences, Inc. Containment System (VBSE$_{TM}$)

Engineered enclosure design and "airfoil" positioning test to containment beyond 1ng ensuring maximum operator safety and balance stability



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Performance Validation

ASHRAE – 110 Tests

Hood ID	*Tracer Gas Left Avg. ppm²*	*Tracer Gas Center Avg. ppm²*	*Tracer Gas Right Avg. ppm²*
2015-1	<0.01	N/A	<0.01
2020-1	<0.01	<0.01	<0.01
2350AC-IP-1	<0.01	N/A	<0.01
2400-1-1	<0.01	<0.01	0.01
3100-1	<0.01	N/A	<0.01
8500-1	<0.01	<0.01	<0.01

Standards

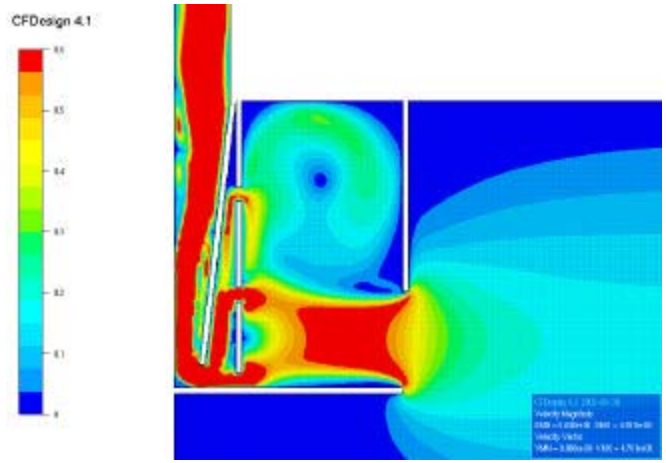
ASHRAE 0.1 ppm ~600,000ng/m^3

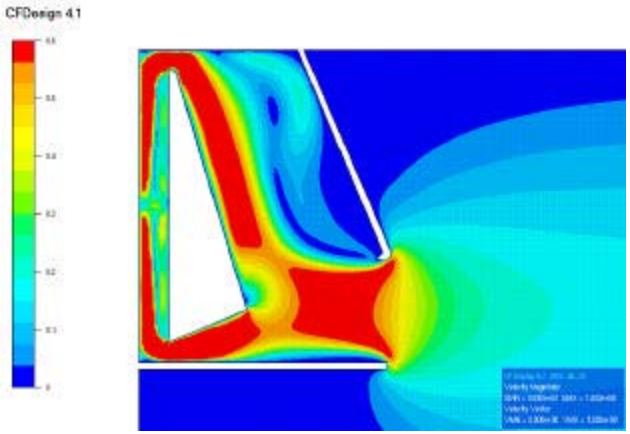
PEL < 1000 ng/m^3

Flow Sciences, Inc. < 5ng/m^3

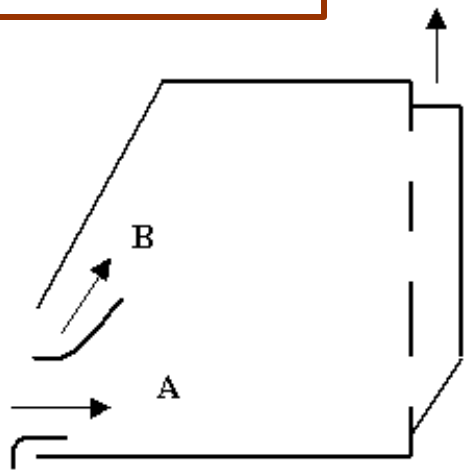
Potential Design Solutions

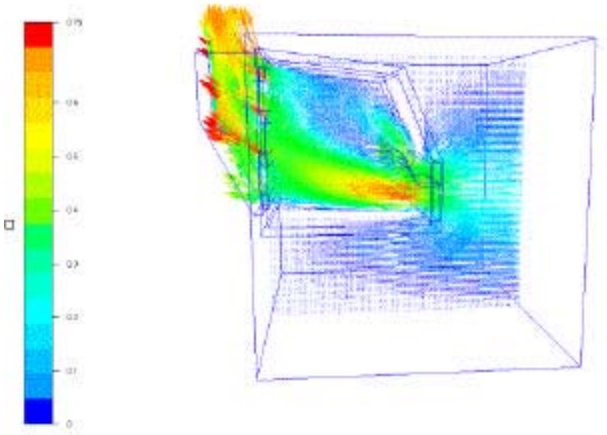
Back baffle design variation





Inflow redirection solution





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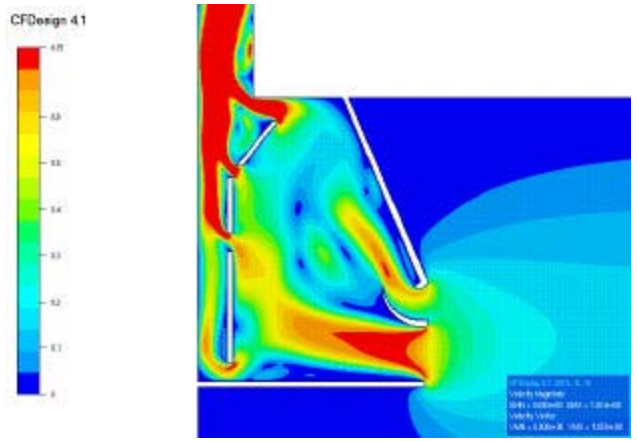
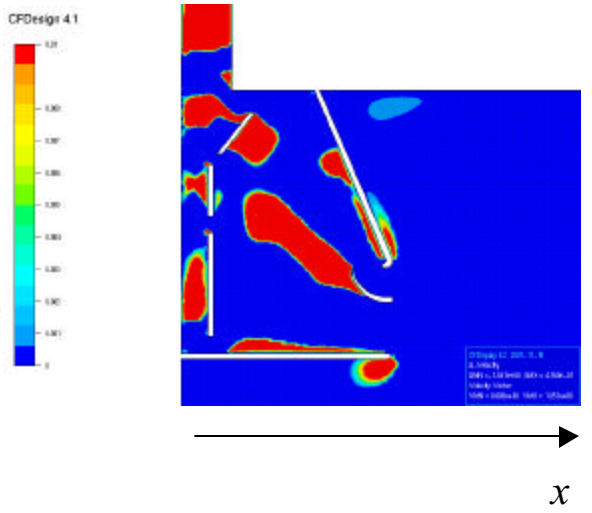
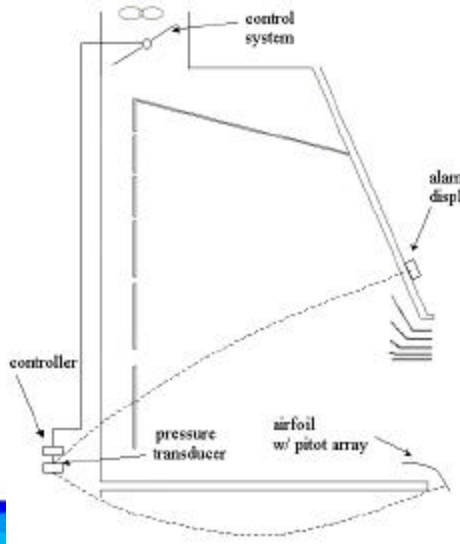
Final Design Detail

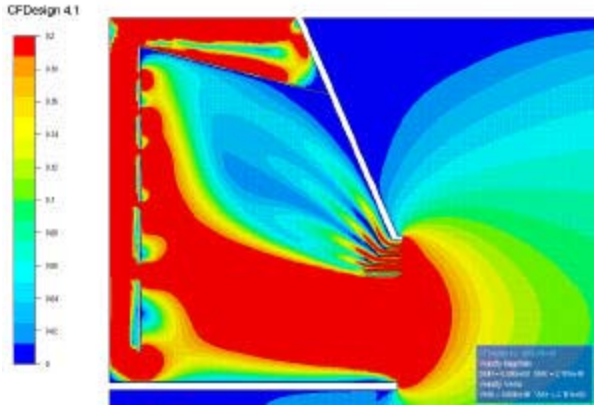
Velocity magnitude profile

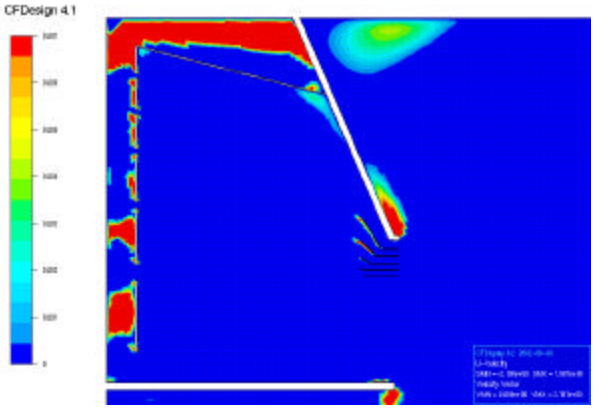


Positive horizontal velocity component









Final design
Patent pending

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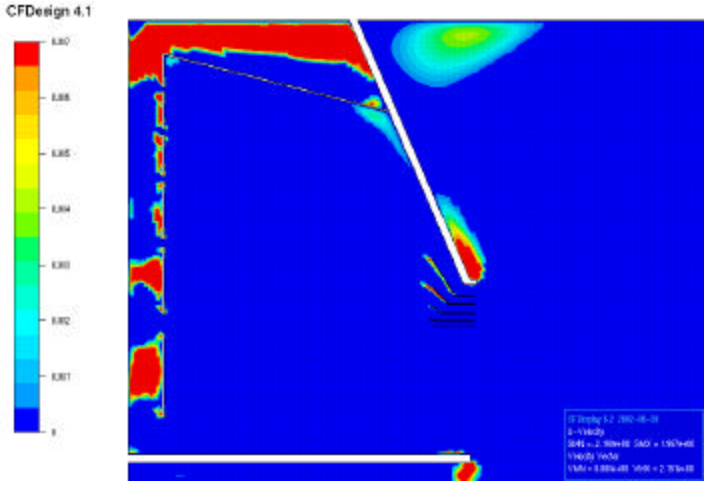
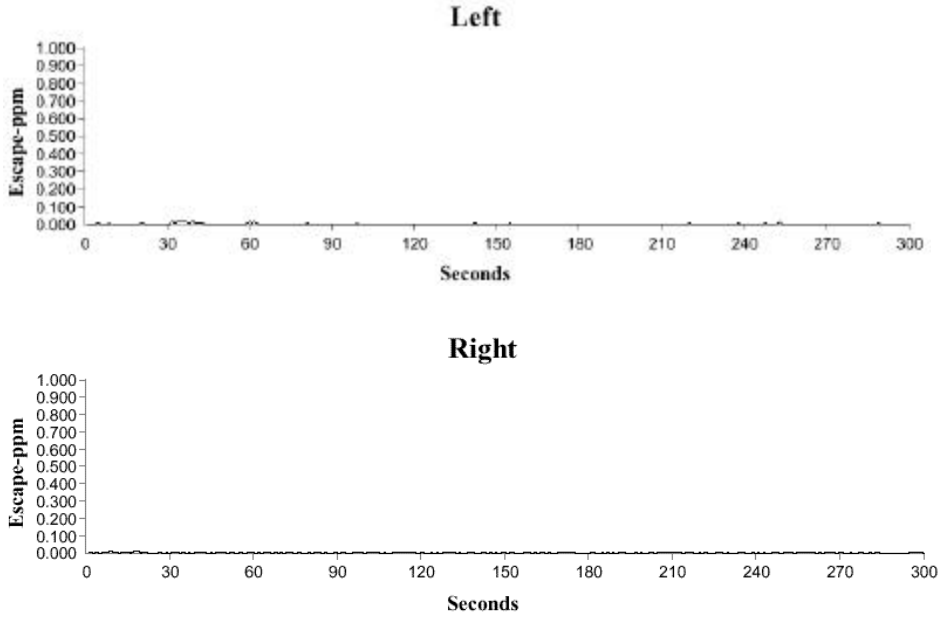
ASHRAE 110 test results at 40 ft/m

Escape characteristics



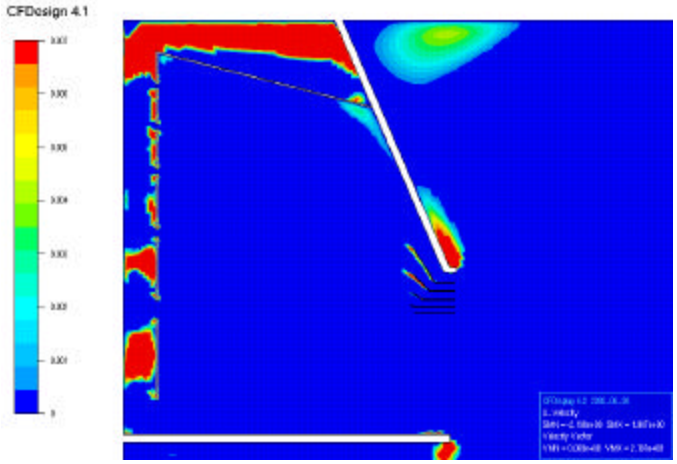


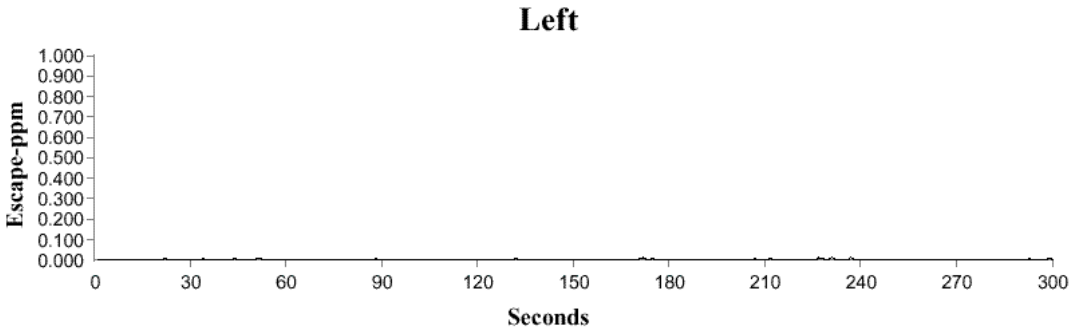
Hood ID	Tracer Gas Left Average ppm	Tracer Gas Right Average ppm
New design	0.00	0.00

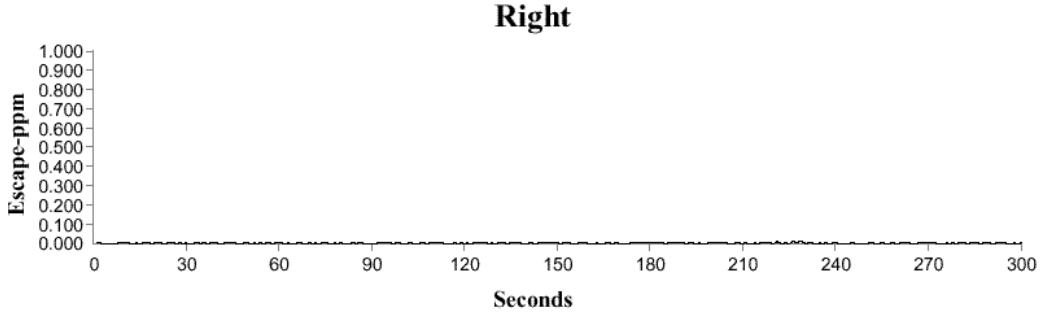
ASHRAE standard 0.1 ppm!!

ASHRAE 110 test results at 80 ft/m

Escape characteristics





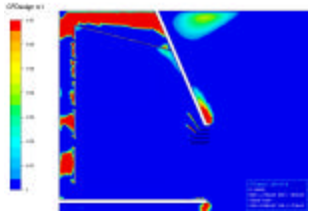


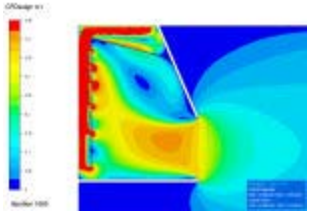
Hood ID	*Tracer Gas Left Average ppm*	*Tracer Gas Right Average ppm*
New design	0.00	0.00

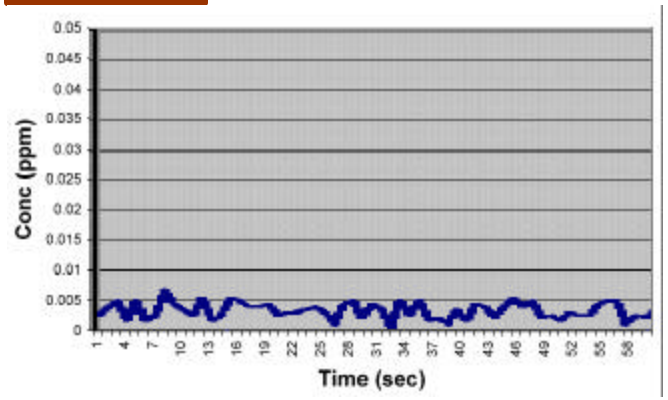
ASHRAE standard 0.1 ppm!!

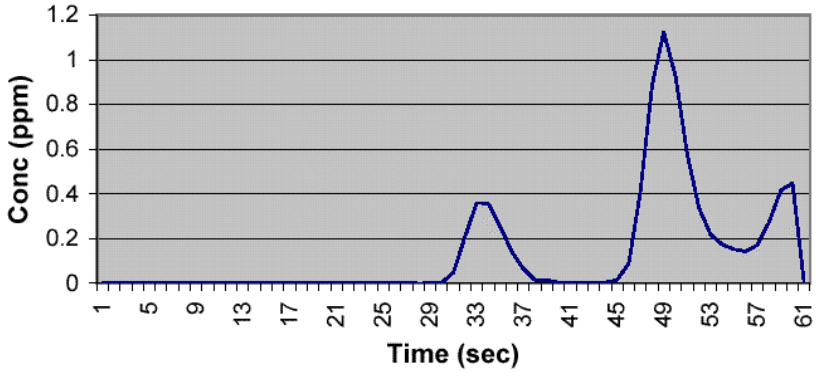
300 ft/m metal plate Blow-by Tracer Gas Test

40 ft/m

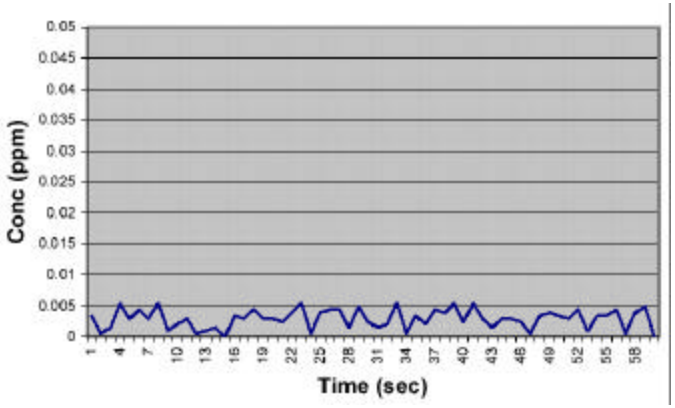


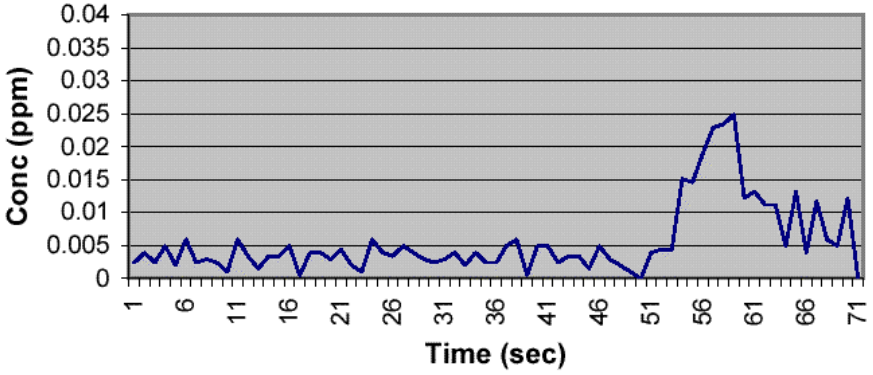






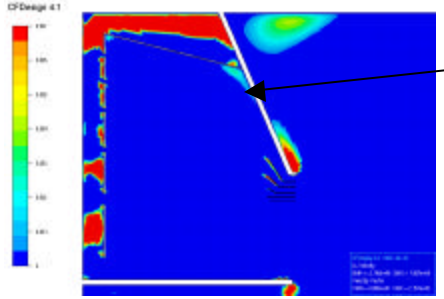
80 ft/m



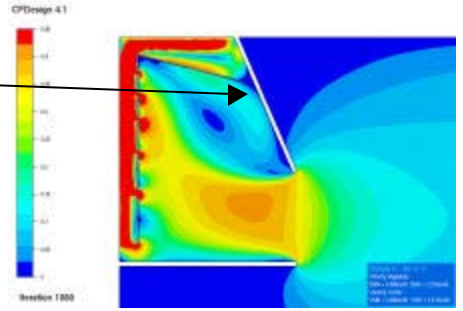


Additional Tracer Gas Challenge

Work area concentration validation



Test position



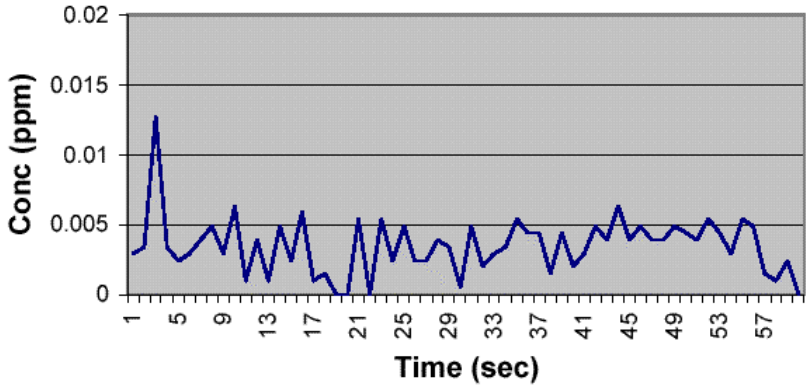
	New Design ppm average	*Traditional Design ppm average*
40 ft/m	3	>120
80 ft/m	3	60

Significant

> 95 – 97.5% reduction of "roll"

Occupied enclosure simulation

- Dynamic equipment re-arrangement test
- Dynamic hood operation test



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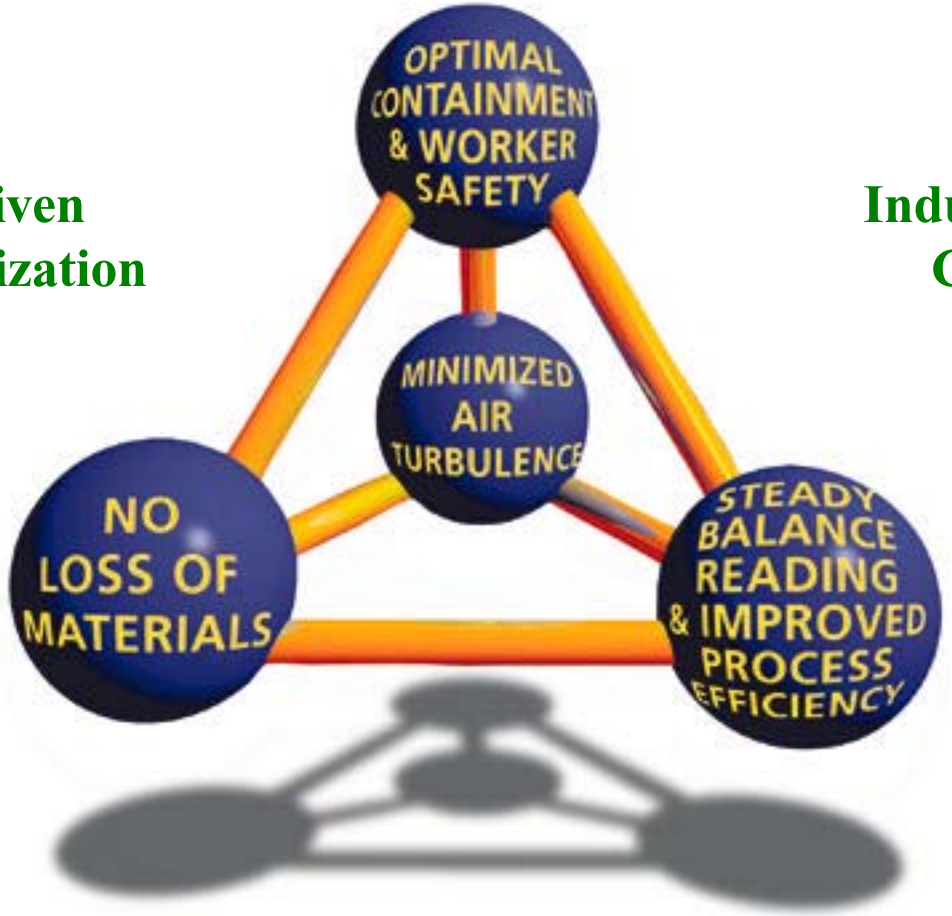
Engineered for Safety and Performance

Rapid Recovery VAV System Validation

Computer Driven Air Flow Optimization



Industry Standard Compliance